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POX, OR PIT (SOIL ROT), OF THE SWEET POTATO

By J. J. TAUBENHAUS

Plant Pathologist and Physiologist in Charge, Texas Agricultural Experiment Station

INTRODUCTION

Next to the blackrot [cause: *Sphaeronema fimbriatum* (E. and H.) Sacc.] and stemrot (causes: *Fusarium batatatis* Wollenw. and *F. hyperoxysporum* Wollenw.), pox, or pit, may be considered as the most important and serious disease of the sweet potato (*Ipomoea batatas*). Until recently the trouble had been misunderstood, having been frequently mistaken for blackrot. For this reason the exact distribution of this disease and the money losses caused by it are not definitely known.

HISTORICAL REVIEW

Pox, or pit, of the sweet potato was first described in 1890 by Halsted (*5*) [1] under the name "soilrot," and was attributed by him to a fungus of a new genus and species named "*Acrocystis batatas* E. and H." Halsted's work was unchallenged for nearly 23 years. In 1913 the writer began the investigation of sweet-potato diseases at the Delaware Experiment Station, first studying the pox of the sweet potato. During the course of the investigation it became apparent that the fungus *Acroscystis batatas* was not the cause of pox, and it further became apparent that in reality the genus Acrocystis was nonexistent and that *A. batatas* was mistaken for another organism. In 1914 the writer (*13*) was the first to call attention to these facts in print. In the summers of 1914 and 1915 much time was spent in an infected field at Felton, Delaware, and more than 1,000 plate cultures were made of the various stages of the disease. At no time did the fungus *A. batatas* ever appear in culture. On the other hand, the predominant flora which constantly appeared were a species of Fusarium, an Actinomyces, bacteria, and a Rhizoctonia. Numerous inoculations of healthy sweet-potato roots in the field and in the greenhouse proved that the bacteria and the species of Fusarium were saprophytic in nature. The species of Rhizoctonia reproduced lesions that were very unlike the typical pox.

[1] Reference is made by number (italic) to "Literature cited," p. 449-450.

The Actinomyces was capable of producing a lesion the appearance of which resembled pox. In January, 1915, the writer severed his relationship with the Delaware Experiment Station, and assumed his present position. A project on sweet-potato diseases was at once undertaken at the Texas Agricultural Experiment Station. Pox was found to be as serious a disease in Texas as in Delaware. Greenhouse work was therefore undertaken as it was not difficult to obtain "sick" soil both from Texas and Delaware. Unfortunately, however, the field work was interrupted that season. At the Delaware Station Dr. J. A. Elliott continued the work of the writer on sweet-potato diseases. He (*3*, *4*) verified the writer's previous conclusion that the fungus *A. batatas* was not the cause of pox. He further found that the disease was induced by a myxomycete of a new genus and species which he named "*Cystospora batata* Elliott." The object of the present paper is to verify Elliott's conclusions, and to add the observations and studies made by the writer.

NAME OF THE DISEASE

The term "soilrot" given by Halsted (*5*) is appropriate only in so far as it indicates that infection takes place on the underground portion of the plant. But it suggests practically nothing as to the nature or symptoms of the disease. In New Jersey the trouble is known to growers of sweet potatoes as "groundrot," a name more suggestive than "soilrot." In Delaware the nature of the disease was only vaguely understood; hence, it was variously known as "bugsting," "wormhole," "fertilizer-burn," and was often mistaken for blackrot. In Texas the disease has no definite name, but it is variously confused with the many root troubles of the sweet potato. In Virginia the disease is known to growers as "pox," or "pit," terms which best describe the trouble, and which were adopted first by the writer (*13*) and later by Elliott (*3*, *4*).

GEOGRAPHIC DISTRIBUTION

There seems no doubt that pox has a wider geographical distribution than is at present known. It can probably be found wherever sweet potatoes grow. In New Jersey, Halsted (*5*) recorded it as a very serious, well-distributed disease. In Delaware it is as yet localized to Kent County, but appears to be gradually spreading southward. In Virginia the pox, although widespread, is at present localized in small areas. In Maryland the disease was recorded by Townsend (*14*), and was found by the writer to be a serious trouble, vying in importance with blackrot. In South Carolina pox was reported by Barre (*1*). In Texas it had been previously reported by Price (*11*); and from the writer's own observation, pox is a serious disease in this State. The same trouble seems also to be prevalent in Alabama, where it was recorded by Wilcox (*15*), and in Oklahoma as reported by Learn (*9*). The disease is also prevalent in Kansas, Prof. L. E. Melchers having recently sent specimens of it to the writer.

ECONOMIC IMPORTANCE

Pox is undoubtedly of great economic importance, but because of inadequate diagnosis estimates of the money losses from the trouble can not be given for all the States where sweet potatoes are grown. In a recent bulletin by Harter (*8*) there is no mention of this disease. This is certainly surprising when we consider the extent of the geographical distribution and economic importance of the disease. It may be safely stated that in fields where pox has become thoroughly established, the yields may be reduced by about 50 to 80 per cent. The writer has had occasion to make such estimates in many sweet-potato fields in Delaware, New Jersey, Maryland, Virginia, and Texas. These observations coincide with those of Halsted (*5*), who states—

> In some large fields visited this season [1890] the loss was almost total.

SYMPTOMS

In the literature pox, or soilrot, is poorly described, the symptoms of the disease not being fully given. The writer's extended field observations on the symptoms of pox may be summarized as follows: In badly affected fields the stand will be somewhat uneven. This, however, may not always be the case. That which attracts the attention most is thin growth, stunted vines, and a pale-green color of the foliage, all of which gives the impression of a very impoverished soil. In fact, growers do not attribute these conditions to the disease, but "to a lack of certain elements in the soil which past sweet-potato crops have removed." Such claims are unfounded, as these soils seem to produce good crops of corn, watermelons, etc. In pulling out a sweet-potato hill from a soil of this character one will be surprised to find an almost total lack of secondary feeding rootlets (Pl. 51, B). This is especially true when the examination is made at the season of maximum growth. Many of the feeding rootlets will be found totally destroyed, while others will exhibit numerous brownish spots at various intervals. Generally speaking, if infection starts at the tip of a growing root, the disease will work its way upward, and destroy that rootlet completely, leaving a discarded stub, which resembles the infected roots of other crops subject to the attacks of species of Thielavia. On the other hand, if infection takes place laterally, the resulting spot will be limited to about 0.1 inch. Frequently such roots may exhibit from 5 to 10 spots, each separated from the others by a healthy area (Pl. 51, A). The color of the spot is a deep chocolate-brown. Such infected rootlets, it is needless to say, become functionless. Besides attacking the feeding rootlets the pox also attacks the small roots which are destined to develop into edible roots (Pl. 51, A). This infection may be as severe and of the same character as in the feeding rootlets. Reduction in yield, lack of the normal green color, and limited vine growth may therefore be directly attributed to the destruction by the disease of the feeding rootlets and young roots.

Infection on the older growing roots may result in a constriction. Growth may seem to cease at this point, although it is uninterrupted on either side (Pl. 52). Infection on the older roots, besides misshaping them, does not, however, result in a total loss. Such roots usually attain a fair marketable size, and do not suffer in the least in edible quality. Here, however, the disease is manifested differently, from that on the young rootlets. On the older roots infection may be of two types.

The normal and typical one is characterized by small, dry, darkish, circular, more or less superficial spots the size of a dime or less. Later, the tissue of the spot in most cases dries up cracks (Pl. 52, A), and falls out, leaving a pox, or pit, whence the name of the disease. As a rule, a new skin is formed immediately below the area of the fallen spot. The depth of the spot seems to vary with the weather conditions; in dry weather the pox spots seem to enter more deeply into the tissue than during wet spells. In light cases of infection, there may be but one to three spots on the potato. In severe cases, however, the spots may be so numerous as to coalesce. These, on dropping out, leave a large, ragged, irregular pit. (Pl. 52, B). The tissue of the pox spot is dry and leathery, but is readily pulverized when rubbed between the fingers.

The second form of infection on the older potatoes is what Elliott (*4*) terms "blister" infection. It was observed by the writer but once; and in that case the infection took place at a feeding rootlet, then worked down to the main root, and was later apparent as a blister-like elevation on the epidermis.

CAUSE AND PATHOGENICITY

It has already been pointed out by the writer (*13*) that Halsted's fungus *Acrocystis batatis*, is not the cause of pox, although species of Rhizoctonia are frequently isolated from pox spots. The fungus, after repeated inoculation, failed to produce the typical disease. It is to the credit of Elliott (*4*) to have proved that pox is caused by a myxomycete *Cystospora batata* Elliott.

The pathogenicity of the organism may be readily proved in the following manner: Mature roots with unbroken pox spots may be easily secured. The roots are then carefully washed in running tap water to remove all trace of soil particles. They are then placed for two minutes in a mercuric-chlorid-alcohol solution,[1] and rinsed several times in sterilized water to remove all trace of the bichlorid. The roots are then placed in the dark in a sterilized moist chamber, heavily lined with clean, wet filter paper. In about 48 hours or more, a dark slimy mass will emerge from the now split pox spot. Upon transferring this slime to healthy sweet potatoes, which have been carefully disinfected and kept in a moist chamber, the typical disease may be reproduced in about three to five days.

[1] Made up of equal parts of mercuric chlorid (1:1,000) and 50 per cent alcohol.

Infection may also be obtained by placing a healthy root whose surface had been sterilized and then placed in contact with the slime developed from a pox spot in the moist chamber, as described above. The ease with which the slime organism may be produced from infected potatoes in the moist chamber should make it excellent material for class work. There seems no doubt that the slime mold *Cystospora batata* is the cause of pox. To prove this definitely, the writer has carried out the following experiment: The slime mold was produced aseptically from young pox spots, as previously described. Bits of the slime were transferred into the tubes of melted and properly cooled agar-agar, and poured into sterile plate dishes. The plates proved sterile, showing that there were no associated organisms in the slime which might be suspected of being the cause of pox. *Cystospara batata* refused to grow on petri plates in hard agar. This explains why the writer had failed in previous attempts to locate the causal organism of pox. In the larger number of plate cultures made, the organism never appeared from the infected tissue. This delayed the progress of the work. *C. batata*, however, may be grown artificially by the following method, suggested by Dr. T. F. Manns, [1] of the Delaware Experiment Station:

> The plasmodium may be grown upon a rich medium of ground up sweet potato, in which about five grams of agar is added per one thousand c. c. Use about 500 grams of such ground up sweet potato in a thousand c. c. of water, leaving as much food as possible in the medium, when made up to 1,000 c. c.

By taking out asceptically bits of tissue from young pox spots, and placing them in a flask in the above medium (sterilized in the autoclave at 15 pounds' pressure for 12 minutes), the organism will make fair growth. To establish further and more definitely the pathogenicity of *Cystospara batata*, six 7-inch pots were filled with typical sweet-potato soil, and sterilized in the autoclave for 12 hours at 20 pounds' pressure. After cooling down, four of these pots were inoculated on June 1, 1917, with the slime grown artificially on the sweet-potato medium in the flask, and the remaining two were left as controls. The inoculum was poured into the four pots and thoroughly mixed in the soil with a sterile spatula. All of the six pots were planted with healthy sweet-potato sprouts, two of the latter to each pot. The pots were kept in the laboratory where there was no possible chance for contamination. After three months all the pots were emptied and the roots in each carefully examined. The roots in the four pots which had been artificially inoculated with the slime grown in flasks showed definite symptoms of pox, whereas the roots in the two control pots were all healthy. This seemed to prove beyond any reasonable doubt that *C. batata* is the cause of pox of the sweet potato. Negative results were always obtained when bits of tissue taken from a pox spot where inoculated into a healthy sweet potato,

[1] Correspondence dated October 26, 1916.

and would seem to indicate that the active plasmodium is necessary for infection. This had already been shown by Elliott (*4*), who, however, also had claimed that infection of the growing tips of the tender rootlets takes place by means of amebæ.

METHODS OF SPREAD

It has already been stated that in dry weather the pox spot seems to be deeper. It is the general opinion of Halsted (*5*), Townsend (*14*), and Duggar (*2*), that pox is worse during dry weather. This in reality is true only in so far as the pox spots are deeper, and cause much more visible damage by distortion and disfigurement of the marketable roots. In wet weather pox is just as severe, and the causal organism perhaps more active, but the spots are more shallow and less noticeable. The roots are not so disfigured, and, hence, are more saleable. According to Halsted (*5*) and others, pox is spread about from field to field by wind-blown spores of the causal organism. The work of the writer does not seem to bear this out. Extended observations and studies have shown that pox does not spread readily from field to field nor even to adjoining neighboring fields by means of wind-blown spores. If it did, the disease would spread very rapidly over large areas. This, however, is not the case. Pox will not become very noticeable until 8 or 10 years after its introduction in a field, and then only when the crop is continually grown on the same land. The disease does not seem to spread rapidly from an infected field to the neighboring fields, but advances slowly, unnoticed and unsuspected. Definite evidence is also lacking as to whether pox is carried over on the small potatoes (seeds) in storage. As a rule, sweet-potato growers never hesitate to plant infected stored seed. According to the writer's observation, and numerous communications from growers, sprouts from such seed, when pulled for transplanting, have not shown evidences of pox on any of the underground portions of the plant. This evidence is further strengthened by Duggar (*2*), who states that—

> Soil rot has not been observed to spread by way of the hot-bed, but only through contamination of the soil of the field.

In order to verify this, the writer has often planted infected seed which wintered over in storage in a sterilized soil. These seeds were surface-sterilized in the usual way. At no time, however, did the resulting sprouts show any marks of pox. The mode of spread of pox needs further careful investigation. It seems reasonable to suppose, however, that the disease is probably disseminated with lumps of soil which have been carried on farm implements on wet days. At that time the sandy soil is more likely to stick together. It is also likely to spread with diseased sprouts which had been grown in a seed bed the soil of which has been taken from a previously infected field. Washing by rain is also likely to carry the disease in the field. In lands with a natural slope pox

will be seen to spread downward in the direction of the water-fall—that is, from the highest to the lowest point—but seldom in the opposite direction.

IS POX A STORAGE TROUBLE?

Elliott (*3*) states that—

> A secondary infection by swarm spores in small immature "pits," causing extensive, blister-like elevations in the skin of stored sweet potatoes, has been observed.

While there seems no doubt of the observation of these blister-like elevations, it seems very probable that the infection did not occur in storage, but late in the field at digging. When these roots were taken in storage, incubation probably was very slow, and because of unfavorable indoor temperature conditions, infection resulted, not in normal spots, but in blisters. In fact, the above supposition is evidently supported by Elliott (*4*) himself in the following statement:

> On infected roots kept in the laboratory, in a dry chamber, a hitherto undescribed secondary infection was observed [referring here to the blister infection].

It seems safe to state that pox is primarily a field trouble, and not a storage trouble. In fact, growers in the infected districts prefer not to sell the infected crop when freshly dug, but to store it over the winter. In the storage house the pox spots dry, and by the time the roots are ready to be shipped, most of them have fallen out. Similar observations are also recorded by Townsend (*14*) and Wilcox (*15*).

OTHER CROPS SUSCEPTIBLE TO POX

As will be seen presently, pox attacks not only the sweet potato but other hosts as well. In the summer of 1914 an old Virginia grower stated to the writer that he never plants white (Irish) potatoes (*Solanum tuberosum*) on the same land where sweet potatoes affected with pox have grown for "the white potato, too, is subject to the same disease." Upon further inquiry it was found that the same practice was observed by most growers there. Bearing this in mind, in 1915 the writer planted Irish potatoes side by side with sweet potatoes in a field badly infected with pox. Observations were made from time to time by pulling out growing plants. Unmistakable symptoms of the pox were noticed at a very early stage. At harvesting, about 60 per cent of the tubers were affected with pox. The symptoms on the Irish potato were no different from those of the pox on the mature roots of the sweet potato (Pl. 51, C-E). However, the spots on the Irish potato seemed to be more shallow. Potato growers in Virginia maintain that some varieties of Irish potatoes seem to be more resistant to pox than others. The Irish Cobbler seems to be the least resistant. This statement is worthy of further investigation. That pox is a serious disease of the Irish

potato there seems no doubt. Dr. T. F. Manns,[1] of the Delaware Station, writes as follows:

> The disease (pox) has proven very severe this year on white potatoes in lower Delaware and Maryland, some specimens being worse than any specimens of scab I believe I have ever seen.

Elliott (*3, 4*), too, has recorded the Irish potato as a host to pox. There seems no doubt that the disease on the Irish potato is far more widespread than has heretofore been recognized; it is very probable also that it has been mistaken and confused with other troubles. Morse and Shapovalov (*10*) and more recently Ramsey (*12*) in their work on the disease caused by *Rhizoctonia* sp., have noticed a pitting disease of the Irish potato that has been attributed to that fungus. No doubt *Rhizoctonia* sp. is abundant in these pits, but from the illustrations given by Morse and Shapovalov (*10*) it is evident that they were dealing with the pox, and that the trouble caused by species of Rhizoctonia was merely secondary.

The writer and Elliott (*4*) have already stated that the pox spots on the Irish potato are of a shallow type; however, under Maine conditions, it is very probable that *Rhizoctonia* sp. merely enters as a result of the injury caused by *Cystospora batata*, and that having once penetrated, it is capable of working in farther, thus deepening the pit. Prof. Ramsey was kind enough to send the writer slides of his so-called "Rhizoctonia pits." In every case these slides were sections of cracked "pits." A careful examination showed a few remaining cysts irregularly scattered in the tissue of the "pit" area. Furthermore, the largest quantity of filaments of *Rhizoctonia* sp. are found in the center, at each side of the crack of the "pit," a place from which the invading plasmodium migrates back to the soil. It seems very probable that the growth of *Rhizoctonia* sp. in the "pits" is limited by the secretion of a toxin which the plasmodium of *C. batata* leaves in the occupied cells before migrating.

Pox on the Irish potato has so far been found to attack the tubers only, and not the roots and rootlets, as it does with the sweet potato. Infection apparently takes place at a lenticel, as Ramsey (*12*) also found.

The turnip (*Brassica rapa*) is also susceptible to pox. In the summers of 1916 and 1917 the writer sowed turnip seed in soil infected with *Cystospora batata*, on which sweet potatoes had been badly diseased. A large percentage of the turnips showed unmistakable pox infection. Here, however, the spots were more superficial than on the Irish potato. It is now suspected that the beet (*Beta vulgaris*) and tomato (*Lycopersicon esculentum*) are also subject to the attack of this disease. Further studies on these two hosts are now in progress.

[1] Letter dated November 15, 1916.

MORPHOLOGY AND LIFE HISTORY OF THE ORGANISM

The gross morphology of *Cystospora batata* has already been indicated by Elliott (*4*). The organism must undoubtedly hibernate in the soil as cysts. This stage probably enables it to resist drouth and cold. Careful experiments by the writer have shown that freezing will not affect *C. batata* in infected soil. Pox-sick soil in flowerpots exposed to outdoor freezing weather during the entire winter will not show the least weakening in the virulency of the causal organism. Similarly, ordinary drying for 12 months will have no injurious effect on *C. batata* in the infected soil.

The cysts are heavy-walled, and each individual may contain large numbers of swarm spores or amebæ. When the latter are ready to emerge, the cyst wall becomes thinner, until finally the swarm spores break through. Infection of the host may take place by the penetration of individual amebæ into the epidermal host cells. This is especially the case with root tips. Ordinarily, however, infection is by means of a plasmodium or of both methods. The swarm spores are round, but slightly tapered at both ends, and possess a single, short flagellum. Occasionally the swarm spores fuse in pairs, but from the writer's observations this has not been the rule. They are usually active after emergence from the mother cyst. The period of activity, although varying from 1 to 7 days, is usually short, often less than 30 minutes. They gradually increase in size, taking on the ameboid, then the plasmodial form. At this stage a large number of nuclei are formed by mitotic division. Nuclear division seems to proceed by a definite mathematical ratio of 1, 2, 4, 8, etc. Single plasmodia may often contain from 200 to 300 nuclei. At this stage and before escaping, the plasmodium becomes more dense, and thickly granular in the center, surrounded by a clearer zone which later becomes a thick cell of the cyst. The latter apparently undergoes a short period of rest, during which time the swarm spores are formed. These in turn emerge and undergo the same life cycle as above described. Thus, in a single infected root tip or in a pox spot, several crops of swarm spores may be formed within the host cells, each generation of which advances farther. Finally all the plasmodia seem to collect, cease advancing, turn backwards, and leave the pit for the soil. It is probable that the plasmodia in the soil encyst and pass the winter in that way. Numerous cytological and morphological studies of this important organism are still in progress.

A NEW SPECIES OF ACTINOMYCES ASSOCIATED WITH POX

Of the many bacteria and fungi isolated from pox, a species of Actinomyces is very often obtained from diseased spots. Because of the persistence of this organism, work was undertaken on it by the writer. Inoculation experiments with pure cultures of this organism showed that

it is capable of producing a spot which, although not resembling pox, may penetrate equally deep in the host tissue. This species of Actinomyces was isolated from sweet-potato material in Delaware, as well as from specimens grown in Texas. Cultures of the organism were grown on various media, and parallel with a strain of *Actinomyces chromogenus* from the Irish potato secured through the kindness of Dr. W. J. Morse, of the Maine Experiment Station. The two organisms appeared to be distinct, and it was thought that the species of Actinomyces grown on sweet potato was a new one, to which the name "*Actinomyces poolensis*, n. sp." was given. Upon submitting a culture of this sweet potato organism to Dr. H. J. Conn, of the Geneva Experiment Station, it was also pronounced by him to be a new species. *A. poolensis* and *A. chromogenus* were grown parallel on numerous culture media in plates and on slants. The greatest differences are observed when the two organisms are grown on potato plugs, corn-meal agar, and on Cook's media No. 2.[1] The difference between the two organisms may be summarized as follows:

	Actinomyces poolensis.	*Antinomyces chromogenus.*
Media No. 2 slants	No color produced in media. Growth slow, thin, flat to undulated up to six weeks after which it becomes more abundant than in *A. chromogenus*. Creamy, glistening, becoming dirty-cream with age.	Media colored from brown to black. Growth rapid. Thick rays, ruffled white. After six weeks, growth slackens, surface becomes brownish.
Corn-meal-agar slants	Media not darkened. Growth abundant, flat, deeply ingrown in substratum. Yellow border with raised white center.	Media not darkened. Growth scant, ingrown in substrata but wavy. Color partially white to gray.
Potato plugs	Potato not colored. Growth slow, thin, wavy, light brown jelly-like, not glistening.	Potato blackened, growth slow, but abundant, spreading, raised, wavy, glistening.

A pure culture of *Actinomyces poolensis* was also submitted to Dr. S. A. Waksman, of the New Jersey Experiment Station, who reported as follows:

> Your second culture, "Pox from sweet potato," has also been isolated by us from several soils. As far as I am aware, this organism has not been described as yet. In a series of biochemical investigations on Actinomyces this organism was found to possess strong proteolytic activities, which may perhaps serve as a clue to its pathogenicity. The cultural characters of this organism are as follows:
>
> A very good growth is produced on different organic media and also on synthetic media containing glucose or glycerine. A good, but uncharacteristic growth was produced on Lubenau's egg medium, Petroff's medium, glycerine, beef infusion agar and Leoffler's blood serum. Growth restricted, cream colored, aerial mycelium gray to

[1] Water (distilled) 1,000 c. c., agar 15 gm., glucose 20 gm., peptone 10 gm., dipotassium phosphate 0.25 gm., magnesium sulphate 0.25 gm.

musty gray on Krainsky's Ca-Malate agar; thin cream colored growth, surface becoming with an ash-gray aerial mycelium, on Czapek's solution agar, in which glucose or glycerine took the place of sucrose, the growth is heavy, yellowish, aerial mycelium abundant, gray (glucose) or (white). No soluble pigment is produced on any of the media studied. On potato plug the growth is light brown, no aerial mycelium is produced, plug is not colored. Milk, at 37° C. is hydrolized in 15 days. Gelatine, at 15° C. is slowly liquified (10 mm. on 20 days), with no color production in the liquefied portion; the growth is light brown, with no aerial mycelium. On glucose broth a flocculent uncharacteristic growth is produced. The organism grows very readily on all the media at 37° C.

Microscopically the following points are to be noted: Spirals are not produced; the aerial mycelium soon breaks up into short cylindrical spores, although many spherical spores are found.

Actinomyces poolensis is a superficial wound parasite, usually found following the pox spots produced by *Cystospora batatas*. The former organism will not grow on healthy tubers of the Irish potato. Structurally *A. poolensis* and *A. chromogenus* differ very little. They can be distinguished only pathologically and when grown parallel on different media.

THE GENUS ACROCYSTIS NOT VALID

In describing pox (soilrot) Halsted (5) has figured a new fungus of a new genus and species which he named "*Acrocystis batatas* E. and Hals." The latter was practically the only described species of the genus Acrocystis. However, Halsted's drawings of Acrocystis are really mistaken figures for *Cystospara batata*, a myxomycete, and not a fungus. Elliott (4) and the writer have proved that pox of the sweet potato is caused by a myxomycete, *Cystospora batata* Elliott. It is therefore evident that *Acrocystis batatas* does not exist at all, and that the genus Acrocystis is not valid.

METHODS OF CONTROL

A careful search through the literature seems to show that Halsted (6, 7) was practically the first to carry out extensive field work on the control of pox. He found that time has a great tendency to increase the spread of pox and at the same time materially to decrease the yield. On the other hand, he discovered that a broadcast application of 300 or 400 pounds of both sulphur and kainit per acre would decrease the disease and also increase the yield of marketable potatoes. The experiments as carried out by Halsted (6, 7) are now being duplicated by the writer in the greenhouse, where conditions are more under control. The work, however, has not progressed far enough to justify any positive statements at this time. From a practical point of view the writer decided to ascertain whether an alkaline or an acid fertilizer would favor or control pox in the field. Accordingly an infested field that had been chosen received normal application of 1,000 pounds per acre of a potash phosphate with the following guaranteed analysis: Ammonia 6 to 8 per

cent, available acid phosphate 7 to 8 per cent, potash 5 per cent. The land was then divided into three plots. The middle remained as a control, and received no further treatment. The plot to the right received an additional application of acid phosphate (guaranteed analysis, 14 per cent of available phosphoric acid) at the rate of 2,000 pounds per acre. The plot to the left received an additional application of hydrated lime (guaranteed analysis, 65 per cent of calcium oxid) at the rate of 2,000 pounds to the acre. The results obtained were very striking. The control plot gave an average of almost 60 per cent affected roots. The lime plot increased the amount of affected roots to about 85 per cent. The percentage of diseased roots in the acid-phosphate plot was 32. This seemed to indicate that an acid fertilizer has a tendency to keep the pox in check, whereas lime has the opposite effect.

The work of the writer would also seem to indicate that there exist considerable differences in the resistance of varieties of sweet potatoes to the disease. Of the limited number tested in 1915 in Delaware the following is a tentative classification of their resistance: (a) Total freedom from disease (Dahomey, Red Brazil, Pearson); (b) from 1 to 20 per cent infected (Big Stem Jersey, White Yam, Yellow Strassberger); (c) from 20 to 90 per cent infected (Goldskin, Big Leaf Upriver).

Steaming the soil for six hours at 20 pounds' pressure will free it from the pox organism. This also seems to be true when the infected soil is treated with formaldehyde at the rate of 1 pint in 20 gallons of water, applied at the rate of 1 gallon of the solution to each square foot of soil space. However, since it is very doubtful if the disease is carried with the seed in the soil of the seed bed, soil sterilization would hardly seem warranted unless it aimed also at controlling blackrot. Likewise it seems hardly necessary to treat the seed for that alone. It is not definitely known how long *Cystospara batata* would persist in the soil without a suitable host. Observations of practical growers differ greatly in this respect. Some assert that at least a 10-year rotation is necessary to free the land from pox; others, and these seem to be in the majority, maintain that a 3-year rotation is sufficient. Soil conditions, it seems, play an important factor. Pox is more severe in the lightest of the sandy soils, and less so in the heavy clay loams.

SUMMARY

(3) Although not definitely known, pox is probably prevalent wherever sweet potatoes are grown. The name "soilrot" does not express the symptoms of the disease and the terms "pox" or "pit" are recommended.

(4) Pox disfigures the root and reduces yields. It destroys the feeding rootlets and many of the roots which otherwise would make the crop.

(5) Infections which result in blisters are apparently the exception, and not the rule, and may be brought about by conditions unfavorable for the parasite.

(6) Pox is caused by a myxomycete, *Cystospara batata* Elliott, and not by the fungus *Acrocystis batatas* E. and H.

(7) The disease may be reproduced at will artificially. Infection can not take place by inserting bits of diseased tissue into healthy parts. The contact of healthy roots with the active slime is necessary for artificial infection. The organism may be grown artificially on culture media.

(8) Pox seems to be equally active in wet and in dry weather. The greatest damage, however, occurs in dry weather, when the roots seem to be more distorted.

(9) In the field the disease does not seem to be disseminated by free-wind-blown spores (cysts) of the causal organism; nor does it seem to be carried over on infected roots kept in storage. It seems to spread with lumps of soil which may adhere to the working tools in wet weather. Evidences also tend to show that the disease is disseminated in the field by rain water.

(10) Pox seems to be a field trouble only.

(11) Pox also attacks the Irish potato and the turnip. The beet and tomato are suspected of being susceptible hosts. There seems little doubt that Morse and Ramsey, in attributing the "pit" disease of the Irish potato to *Rhizoctonia* spp., were in reality dealing with pox, the injury by *Rhizoctonia* spp. being merely secondary.

(12) *C. batata* probably hibernates as cysts in the soil.

(13) A new species of Actinomyces, *A. poolensis* Taubenhaus, is found associated with the *C. batata*. The former acts only as a wound parasite and secondary invader.

(14) The genus Acrocystis, as originally described by Halsted, is not valid and is nonexistent. The fungus *Acrocystis batatas* was mistaken by Halsted for a myxomycete which Elliott has named "*Cystospora batata*," the true cause of pox (soilrot).

(15) The red varieties of the sweet potato seem to possess the greatest resistance to pox.

(16) Soil sterilization of the soil of the seed bed to control pox is not recommended. Rotation of crops tends to decrease the disease in a sick soil. The rotation remains to be worked out.

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PLATE 51

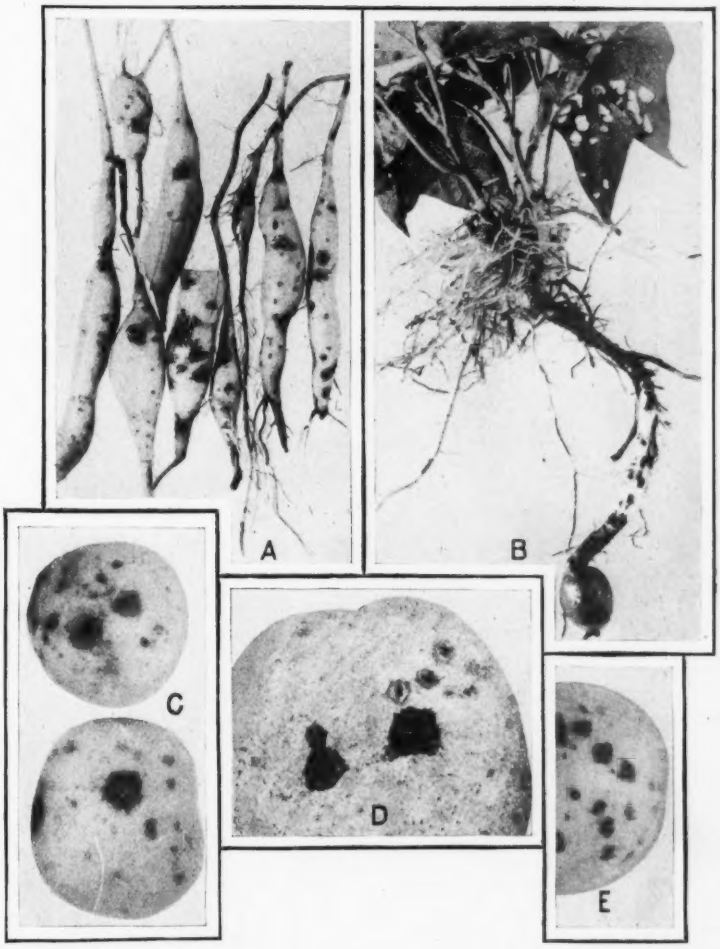
A.—Young sweet-potato roots affected with pox spots.

B.—Sweet-potato sprouts, the lower rootlets of which have been totally destroyed by pox.

C.—Typical pox spots on tubers of the Irish potato.

D.—Pox spots of the Irish potato (after Ramsey).

E.—Pox on Irish potato showing lenticel infection.


A
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C
D
E

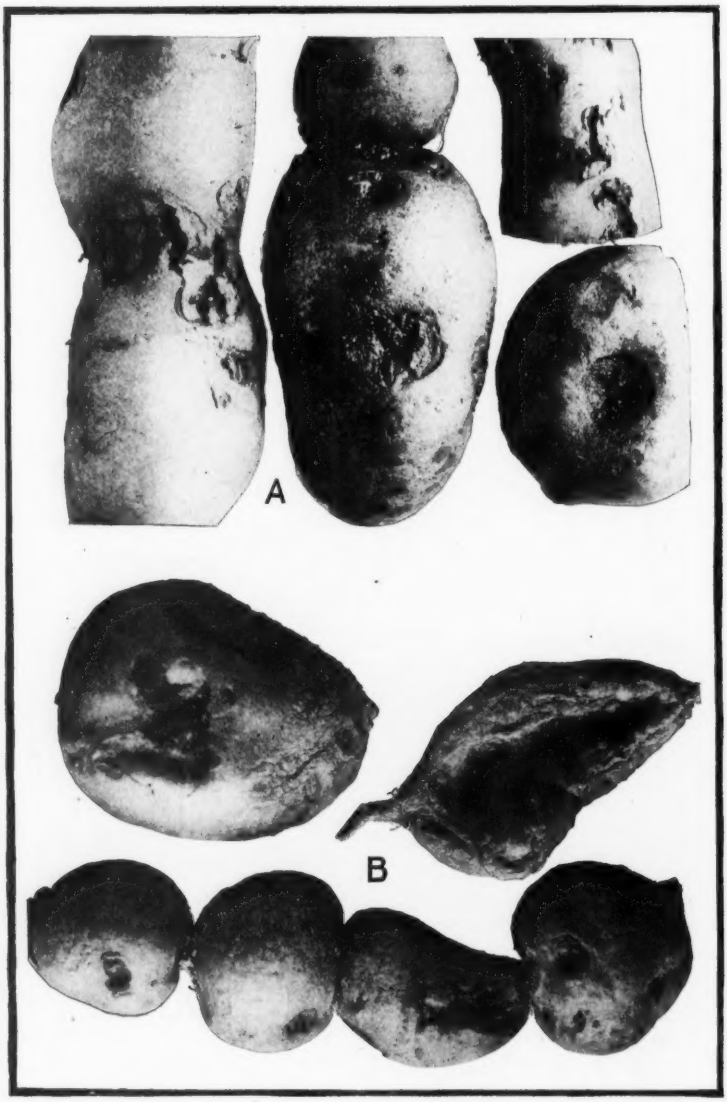
A
B

PLATE 52

A.—Sweet potatoes showing the typical pox spots and cracking previous to the falling out of affected tissue.

B.—Top row: Sweet potatoes showing the large pits formed as a result of a heavy infection, and later by the falling out of the pox spots. Bottom row: Sweet potatoes showing the constricted effect and uneven growth of the root as a result of early infection.

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BORON: ITS EFFECT ON CROPS AND ITS DISTRIBUTION IN PLANTS AND SOIL IN DIFFERENT PARTS OF THE UNITED STATES

By F. C. Cook and J. B. Wilson, *of the Animal Physiological Chemical Laboratory, Bureau of Chemistry, United States Department of Agriculture*

INTRODUCTION

The results reported in this paper are a continuation of the experiments previously recorded (*2*, *3*, *4*),[1] dealing with the effect on the growth of crops of borax and colemanite (calcium borate) when added to horse manure in amounts sufficient to kill the larvæ of the house fly, with particular reference to the action of boron-treated manure when applied to the same soil for two or three consecutive seasons. It was thought that crops that had not been injured by the first addition of the boron-treated manure might be injured by a second or third application. A study was made of the effect on crops and soil of large amounts of boron-treated manure such as might be used by truck growers to force crops. In this way the tests covered the application of the largest possibly amounts of boron-treated manure to soil which might possibly be made through any combination of circumstances.

GENERAL PLAN OF EXPERIMENTS[2]

In all tests 0.08 pound of borax or 0.095 pound of colemanite per bushel of manure were used. These quanities are sufficient to act as a larvicide for the house fly. When 0.08 pound of borax is added to the bushel of manure and applied at the rate of 16 tons to the acre, it is calculated, by assuming that the weight of the upper 6 inches of soil per acre is 1,750,000 pounds, that 0.00176 per cent of boron as boric acid (H_3BO_3) is present in the upper 6 inches of the soil. When the above quantity of colemanite is added to the manure, 0.00232 per cent of boric acid is estimated to be in the upper 6 inches of soil. If the treated manure is applied at the rate of 24 and 40 tons to the acre, it is calculated that 0.00264 and 0.0044 per cent, respectively, of boric acid are present in the upper 6 inches of soil when borax is added. When colemanite is added, 0.00348 and 0.0058 per cent, respectively, of boric acid are present in the same amount of soil.

The action of both borax-treated manure and colemanite-treated manure on barley and peach trees in California and on wheat at Benton

[1] Reference is made by number (italic) to "Literature cited," p. 470.

[2] The experiments were carried out with the cooperation of Mr. W. D. Hunter, of the Bureau of Entomology.

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Harbor, Mich., was tested during the season of 1914–15. In these experiments but one application of the boron-treated manure was made, and the observations extended over only one season. The manure was applied to the soil at the rate of 16 tons per acre. The amount of boric acid calculated to have been added to the soil is given above.

Experiments were inaugurated in 1914 on the experimental farm of the Bureau of Plant Industry at Arlington, Va., and on the farm of the Bureau of Animal Industry at Bethesda, Md. The Arlington experiments extended over two seasons; those at Bethesda over three seasons. The manure was applied to the soil at the rates of 16, 24, and 40 tons per acre. (The percentage of boric acid in the different plots is given on p. 451.) Nine plots were used at each place: Three for borax-treated manure, three for colemanite-treated manure, and three for untreated manure. In all cases the boron was well incorporated with the manure, and the mixture then stood in piles for 10 days before it was spread on the plots. The ground was lightly plowed, harrowed, and rolled. Different vegetables were grown on the plots the first two seasons. Rye was grown the third season on all plots at Bethesda.[1]

In order to obtain additional information in regard to the length of time that boron can be detected in soils, samples of soils which had received applications of boron-treated manure in 1914 and which had been tested for soluble boron in 1915 were taken in 1916 from the plots at Orlando, Fla., New Orleans, La., and Dallas, Tex.

EXPERIMENTAL METHODS USED

Boron was estimated in the plants and soil as boric acid, with the methods described by one of the writers (*2*). This procedure involved the use of strips of curcumin paper, and a comparison of the color obtained from extracts of the ash of the plants and fruit and extracts and fusion mixtures from the soil, with the color from standard solutions of boric acid. Both total and acid-soluble boron were estimated in the soil.

The methods of the Association of Official Agricultural Chemists [2] for solids, total nitrogen, and for nitrogen as ammonia on distillation with magnesium oxid were used. The Folin and McCallum aeration method for ammonia [3] and the aluminum-foil reduction method for nitrates [4] as adopted by the American Public Health Association were employed.

[1] The cooperation of Dr. E. C. Schroeder, of Bethesda, and of Messrs. Butterfield and Criswell, of the Arlington Farm, was of great assistance.

[2] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. REPORT OF THE COMMITTEE ON EDITING TENTATIVE AND OFFICIAL METHODS OF ANALYSIS. 381 p., 15 fig. Baltimore, 1916.

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EFFECT OF BORAX AND COLEMANITE ON PEACH TREES

Boron-treated and colemanite-treated manures were applied to the soil of separate groups of peach trees (*Amygdalus persica*) in an orchard at Acampo, Cal., in November, 1914. A third group of trees was fertilized with untreated manure, and a fourth group was left unfertilized. A total of 100 trees were included in the experiment. The work was done under the supervision of Mr. R. L. Nougaret, of the Bureau of Entomology. The orchard was planted in the spring of 1913. The manure was applied at the rate of 16 tons per acre. The amounts of boron and colemanite added to the manure are given on page 451. In the fall of 1915 the groups of fertilized trees could be easily distinguished from the other trees in the orchard because of the vigorous growth and dark-green color of the foliage. The dark-green foliage was particularly marked in the case of the trees fertilized with borax-treated manure, the foliage of the trees fertilized with colemanite manure being somewhat less green, while the foliage of the unmanured trees was the least green. Three nurserymen having no knowledge of the nature of the experiment passed judgment on the length of the growth of new wood, the fruit buds, and the general condition of the trees. All of the trees treated with either borax-treated or colemanite-treated manure were given the highest ratings, while many of the trees fertilized with untreated manure or left unfertilized were given lower ratings.

Samples of soil from the experimental section of the orchard were tested for boron. No acid-soluble boron was found in any of the soils, but there was a small amount of total boron in all of the soils. The results are recorded in Table I and are in agreement with the results of the analyses of other soils in showing the absence of detectable amounts of soluble boron.

TABLE I.—*Percentage of soluble and total boron in soil samples, Acampo, Cal., 1915*

Boric acid added to upper 6 inches of soil.	Soluble boron as boric acid found.	Total boron as boric acid found.
Per cent.	*Per cent.*	*Per cent.*
0.00176 as borax	0	0.00003
0.00232 as colemanite	0	.00001
Control	0	.00001

BARLEY EXPERIMENTS

The effect of borax and colemanite on the growth of barley (*Hordeum* spp.) was studied at Walnut Creek, Cal., by Mr. Nougaret. In these experiments the manure was also applied at the rate of 16 tons per acre. Three plots were used for the test, one fertilized with borax-treated manure, one with colemanite-treated manure, and a third with untreated

manure. The amount of borax and colemanite added to the manure is given on page 451.

No injurious effect of the boron was noticeable during the growing period. The yields were not determined, but so far as could be estimated, the borax and colemanite did not affect the yields. The crop was harvested in June, 1915. At the time of harvest samples of grain and straw from each plot were analyzed for solids, nitrogen, and boric acid. The results are given in Table II.

TABLE II.—*Percentage of solids, nitrogen, and boron in barley, grain, and straw, dry basis, Walnut Creek, Cal., 1915*

Boric acid added to upper 6 inches of soil.	Material.	Solids.	Nitrogen.	Total boron as boric acid found.
Per cent.		*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax	Straw	93.97	0.34	0
	Grain	91.75	1.52	.00001
0.00232 as colemanite	Straw	93.26	.27	.00001
	Grain	90.00	1.46	.00002
Control	Straw	91.78	.41	.00001
	Grain	91.75	1.59	0
Control (between rows)	Straw	92.44	.52	.00002
	Grain	91.93	1.43	.00001

The nitrogen in the grain was practically equal in all samples, while the two samples of straw grown on the boron-treated plots contained less nitrogen than the two control straw samples. Only minute amounts of boron were found in the barley, either straw or grain. The control samples showed the presence of as much boron as there was in the barley grown on soil to which boron was added. No injurious action of the added boron was apparent.

In this connection the difference in the effect of boron in nutrient solution as compared with that in field experiments is illustrated by the findings of Brenchley (*1*) at the Rothamsted station. She found boric acid to be definitely poisonous to barley down to 1 part in 250,000.

Samples of soil were taken from each of the three plots and analyzed for soluble and total boron. The results are given in Table III.

TABLE III.—*Percentage of soluble and total boron in soil samples from Walnut Creek, Cal., 1915*

Boric acid added to upper 6 inches of soil.	Soluble boron as boric acid found.	Total boron as boric acid found.
Per cent.	*Per cent.*	*Per cent.*
0.00176 as borax	0	0.00008
0.00232 as colemanite	0	.000024
Control	0	.00004

More total boron was present in the control sample than was found in one of the two treated samples. The control showed four times as much boric acid as the control from the peach orchard at Acampo, Cal.

WHEAT EXPERIMENTS

Similar experiments were tried testing the effect of borax and colemanite on the growth of wheat (*Triticum* spp.) at Benton Harbor, Mich., during the season of 1914–15. The same amounts of borax and colemanite were added as in the two previous tests. Mr. F. L. Simanton, of the Bureau of Entomology, directed these experiments. No effect of the boron was evident during the growth of the crop; nor were the yields influenced by the added boron. Samples of grain and straw were taken from all three plots in June, 1915, and analyzed for solids, nitrogen, and boric acid. Samples of wheat stubble were also analyzed. The results are given in Table IV.

TABLE IV.—*Percentage of solids, nitrogen, and boron in wheat grain and straw, dry basis, Benton Harbor, Mich., 1915*

Boric acid added to upper 6 inches of soil.	Material.	Solids.	Nitrogen.	Total boron as boric acid found.
Per cent.		*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax	Straw	94.04	0.42	0.00267
	Grain	89.40	1.97	.0008
0.00232 as colemanite	Straw	93.07	.52	.00016
	Grain	89.76	2.15	.00016
Control	Straw	92.84	.35	.00040
	Grain	88.91	1.69	.00012
0.00176 as borax	Stubble, second growth	94.17	.....	.0020
	Roots of stubble, second growth.	94.64	.....	.00036
0.00232 as colemanite	Stubble, second growth	94.47	.....	.0040
	Roots of stubble, second growth.	96.35	.....	.00001
Control	Stubble, second growth	94.42	.....	.00001
	Roots of stubble, second growth.	94.90	.....	.00001

There was less nitrogen in the grain and straw from the control plot than from the boron-treated plots. The grain contained less boric acid than the straw. It is apparent that the wheat, both grain and straw, took up more boron from the borax-treated than from the colemanite-treated plot. The roots of the stubble contained much less boric acid than the tops. The amount of boric acid in the stubble from the control plot was much less than in the control straw of the first growth of wheat on the same plot.

At the time the wheat samples were taken soil samples were also obtained. Analyses of these samples are reported in Table V.

TABLE V.—*Percentage of boron in soil samples from Benton Harbor, Mich., 1915*

Boric acid added to upper 6 inches of soil.	Soluble boron as boric acid found.	Total boron as boric acid found.
Per cent.	*Per cent.*	*Per cent.*
0.00176 as borax	0	0.00004
0.00232 as colemanite	0	.00012
Control	0	.00003

As in the other samples of soils analyzed, no soluble boron was present. More total boric acid was found in the sample from the colemanite than in the sample from the borax plot. The amount of boric acid in the control soil was practically the same as found in the control plot of the barley experiments at Walnut Creek, Cal.

EFFECT OF TWO APPLICATIONS OF BORON-TREATED MANURE ON VEGETABLES

Nine plots, each 29.7 by 40.74 feet, with 3-foot guards were used for these experiments at Arlington Experimental Farm. Three of the plots received manure containing added borax; three of them received similar applications of manure containing added colemanite; while the remaining three plots received untreated manure. The amounts of boron added to the plots are given on page 451.

EXPERIMENTS OF THE FIRST SEASON, 1914

Six rows of spinach (*Spinacia oleracea*) and six rows of kale (*Brassica oleracea acephala*) per plot were planted on October 1, 1914. On this date young cabbage (*Brassica oleracea capitata*) and lettuce (*Lactuca sativa*) plants, two rows each per plot, were set out. On October 9 it was evident that the boron had not prevented germination, as spinach and kale plants appeared above the ground on all plots. The lettuce and cabbage plants were normal. On November 10 it was evident that the spinach and kale plants were not as numerous on all the 24- and 40-ton plots as on the 16-ton plots. No signs of burning were observed on any of the plots. No injurious action of the boron was evident in the early spring of 1915. The majority of the lettuce and cabbage plants did not survive the winter, but the spinach and kale looked normal.

ANALYSES OF VEGETABLES AND SOIL

On June 26, 1915, lettuce, cabbage, spinach, and kale plants, also samples of the soil 6 inches deep, were taken from the different plots. The results of the analyses of the vegetables are given in Table VI, and the soil results in Table VII. The methods used were those described on page 452. The tops of all varieties of the plants contained more boron when grown on the 40-ton plots than when grown on the 16- or 24-ton plots. All the roots gave negative results for boron. More boron was

absorbed by the plants grown on the 40-ton colemanite-treated plot when the boron was added as the insoluble calcium colemanite than when grown on the 40-ton borax plot where the boron was added in a readily soluble form. The control samples tested were remarkedly free from boron, only the tops of the kale showing any traces. The flowering tops of the kale contained about the same amount of boron as the rest of the tops of the plant. Nakamura (7) found that 0.0001 per cent of boric acid in culture solutions stimulated spinach, but had a slightly injurious action on peas.

Five samples of soil, two from each of the light and the heavy boron-treated plots and a control sample, were analyzed for nitrates, ammonia, and soluble boron.

TABLE VI.—*Percentage of the total boron as boric acid in lettuce, spinach, cabbage, and kale, dry basis, Arlington, Va., 1914–15*

Boric acid added to upper 6 inches of soil.	Parts of plants analyzed.	Boric acid found.			
		Lettuce.	Spinach.	Cabbage.	Kale.
Per cent.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax (16-ton plot).	Tops	.....	0	Trace	0
	Roots	.....	0	0	0
	Flowering tops	.....	.....	.....	.00025
0.00264 as borax (24-ton plot).	Tops	Trace	.....	0	.....
	Roots	0	.....	0	.....
	Flowering tops	.....	.....	.....	.....
0.0044 as borax (40-ton plot).	Tops	.0002	.002	Faint trace.	.001
	Roots	0	0	0	0
	Flowering tops	.....	.....	.....	.0014
0.00232 as colemanite (16-ton plot).	Tops	0	.001	.004	.....
	Roots	0	0	0	.....
	Flowering tops	.....	.....	.....	.....
0.00348 as colemanite (24-ton plot).	Tops	0	.....	.00006	.....
	Roots	0	.....	0	.....
	Flowering tops	.....	.....	.....	.....
0.0058 as colemanite (40-ton plot).	Tops	.00225	.0085	.00475	.00625
	Roots	0	0	0	0
	Flowering tops	.....	.....	.....	.00365
40-ton control	Tops	.....	0	0	.0001
	Roots	.....	0	0	0
	Flowering tops	.....	.....	.....	0

TABLE VII.—*Percentage of nitrate and ammonia nitrogen and soluble boron in soil samples, Arlington, Va., 1915*

Boric acid added to upper 6 inches of soil.	Nitrate nitrogen.	Ammonia nitrogen.[1]	Soluble boron as boric acid found.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax (16-ton plot)	0.00133	0.0016	0
0.0044 as borax (40-ton plot)	.01106	.0023	0
0.00232 as colemanite (16-ton plot)	.00138	.0016	0
0.0058 as colemanite (40-ton plot)	.00216	.0021	0
40-ton control	.00263	.0017	0

[1] Folin method.

It is evident from the negative soluble boron results that the boron is combined in an insoluble form in the soil, although much of it is undoubtedly held in levels lower than the first 6 inches of soil The nitrate results for the soil from the boron-treated plots are, with the exception of the 40-ton borax-treated plot, a little lower than in the control plot. The amount of ammonia in the boron-treated samples averages higher than that in the control soil.

EXPERIMENTS OF THE SECOND SEASON, 1915

Soon after the samples had been taken from the plots on June 26, 1915, the ground was again fertilized with manure treated as before—that is, the same amounts of boron-treated and untreated manure were added to their respective plots and it was plowed under and the ground harrowed and rolled. On July 15 corn (*Zea mays*), turnips (*Brassica rapa*), and pea beans (*Phaseolus vulgaris*) were planted. On August 10 it was apparent that the beans grown on the plots to which boron-treated manure had been added had been severely injured. The turnips on the 16-ton boron-treated plots were normal, but were thinner on the 24- and 40-ton boron-treated plots than on the corresponding controls. The growth of corn was irregular on all the plots, but no yellowing from the boron was apparent. The beans showed a yellowing on all the plots. The turnips that came up on the 24- and 40-ton plots showed no yellowing. The growth of all the vegetables was poor on all the 40-ton plots, and a marked reduction in the crop yield was evident on the 24-ton plots, especially where boron had been added to the soil. On September 7 the plants on the 16-ton plots were in a fairly good condition. The only injury to any of the plants on these plots that may be attributed to the boron was a yellowing of the bean plants. On the 24-ton plots none of the crops were doing well, although the control was undoubtedly the best of the three plots. The beans were injured and the growth of the turnips was irregular, especially on the borax-treated plot. The corn showed a reduced stand as one effect of the added boron. The 40-ton boron treatments had injured all the crops, the beans severely, the turnips and corn considerably. The crops on the 40-ton control plot were poor and showed some injury.

One row (the middle row) of corn and of beans were pulled from each plot and weighed by Mr. Rhodes, of the Arlington farm, in October, 1915. These weights, given in Table VIII, represent the whole plants, including the roots.

The weights of beans and corn given in Table VIII indicate a greater influence of the 24-ton boron-treated manure plot than was evident from the observations reported above. While the amount of boron in the manure did not produce any outward evidence of injury on corn, it seriously affected the yield. It is also evident that the untreated manure

when added at the 24-ton rate reduced the yield markedly over the yield on the plots fertilized at the 16-ton rate. With the control the reduction of the 24-ton over the 16-ton plot was proportionately greater than with the 40-ton over the 24-ton plot. With the boron-treated plots the marked action of the 40-ton applications is shown by the practical destruction of the bean crop and the marked reduction of the yield of corn.

TABLE VIII.—*Weights of one row of whole bean and corn plants at Arlington Experimental Farm, 1915*

Boric acid added to upper 6 inches of soil.	Beans.		Corn.
Per cent.	*Lb.*	*Oz.*	*Lb.*
0.00176 as borax (16-ton plot)	3	1	37
0.00264 as borax (24-ton plot)	2	12	17
0.0044 as borax (40-ton plot)	0	9	14
0.00232 as colemanite (16-ton plot)	12	9	54
0.00348 as colemanite (24-ton plot)	3	5	21
0.0058 as colemanite (40-ton plot)	0	5	15
16-ton control	15	1	48
24-ton control	9	10	29
40-ton control	7	4	30

On October 5 samples of turnips from the 16- and 40-ton borax-treated manure plots and from the 40-ton control plot were collected and tested with the results given in Table IX.

TABLE IX.—*Percentage of boron in turnips, dry basis, at Arlington Experimental Farm, 1915*

Boric acid added to upper 6 inches of soil.	Parts of plants analyzed.	Total boron as boric acid found.
Per cent.		*Per cent.*
0.00176 as borax (16-ton plot)	Tops	0.0036
	Roots	.0012
0.0044 as borax (40-ton plot)	Tops	.0032
	Roots	.0017
40-ton control	Tops	.0020
	Roots	.00002

The tops contained the greater portion of the boron. The boron in the roots varied directly with the boron added to the soil, whereas in the tops this was not the case. On comparing these results with the results reported in Table VI for the plants grown on these plots after the first application of manure containing added boron, it is evident that no more boron was taken up by the turnips grown after the second application of boron-treated manure than by the plants after the first application.

Samples of soil were taken from these plots on October 5 and tested for solids, nitrate and ammonia nitrogen, and total and soluble boron. The results are given in Table X.

TABLE X.—*Analyses of soil samples from Arlington Experimental Farm, 1915*

Boric acid added to upper 6 inches of soil.	Solids.	Nitrogen as nitrates.	Nitrogen as ammonia (Folin method).	Soluble boron as boric acid found.	Total boron as boric acid found.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax (16-ton plot).....	82. 43	0. 0049	0. 00042	0	0. 00010
0.0044 as borax (40-ton plot).....	82. 13	. 0056	. 00083	0	. 00014
40-ton control.....	79. 85	. 0051	. 00083	0	. 00005

No effect which may be attributed to the boron is evident from the results given in Table X. It is known that in cases of excessive applications of manure, as in the two 40-ton applications reported above, normal bacterial metabolism does not take place. This may account for the lack of evidence of the influence of the boron on the nitrogen constituents of the soil. No soluble boric acid and only small amounts of total boric acid were found in the soil. The absence of soluble boron is in agreement with the first year's findings.

It is evident that there is no accumulation of boron in the upper 6 inches of soil following two heavy applications of borax to the soil within one year.

EFFECTS OF THREE APPLICATIONS OF MANURE CONTAINING BORON ON CROPS AND SOIL

Experiments to determine the effect of three applications of boron-treated manure on crops and soil were carried out on the farm of the Bureau of Animal Industry at Bethesda, Md., in 1914, 1915, and 1916. A plot of ground 206 feet long and 60 feet wide was selected. The experiments were similar to those at the Arlington Experimental Farm and included three successive applications of horse manure containing added borax and of manure containing added colemanite to the same soil and their influence on the crops grown thereon. Nine plots were used, and the treated and untreated manure was applied at the rate of 16, 24, and 40 tons per acre. The amount of boron added is given on page 451. Guards 3 feet wide separated all the plots. The distribution of the boron in different parts of the crops grown on the various plots and its effect on the nitrogen distribution in the soil were also studied.

EXPERIMENTS OF THE FIRST YEAR, 1914

On October 1, 1914, kale, lettuce, and spinach seeds and onion (*Allium cepa*) sets were planted in all the plots. Notes taken at different times following the planting showed that all plots looked equally well. In April, 1915, it was seen that the lettuce had not survived the winter but the kale, spinach, and onions were growing. No injury and no variation in the growth on any of the plots were seen. It was apparent that the

boron, either as borax or as calcined colemanite, had exerted no ill effects on the growth of these crops. Samples of onions were taken from the various plots for analysis for boron in July, 1915. They had gone to seed; and the flowering tops, as well as the tops and roots, were tested. The flowering tops from the borax treated plot, where the manure had been applied at the 40-ton rate showed 0.00004 per cent of boric acid. The rest of the plants or portions of plants gave negative results for boron. Jay (*6*) reported that he found considerable amounts of boron in onions. As will be seen later, none of the plants grown at Bethesda absorbed much boron.

EXPERIMENTS OF THE SECOND YEAR, 1915

The plots were cleared, and a second application of manure was made to all plots on July 1, 1915, with the same quantities of borax and colemanite and three different rates of manure application as the first year—that is, the plots received exactly the same amounts of boron as in September, 1914. The manure was harrowed into the ground, not plowed, so as to have the boron in the upper 3 or 4 inches of soil in order to obtain the maximum effects. On July 12, 1915, Golden Bantam corn, green stringless beans, table beets (*Beta vulgaris*), and McCormick potatoes were planted. On July 29 the corn, beets, and beans were up, and a potato plant was seen here and there. The beans showed a yellowing on the borax-treated and colemanite-treated plots, even where the manure was applied at the 16-ton rate. During August the beans growing on the 40-ton borax-treated plots showed decided injury, while those on the 16- and 24-ton plots showed some injury. Colemanite prodiuced much less injury to the beans than the borax. There were fewer potato plants on the plot where borax manure was applied at the 40-ton rate than on the other plots. It was very noticeable during August that no weeds were growing on the colemanite plots, while weeds grew luxuriantly on the control and the borax treated plots.

On August 20 the beets, as well as the beans, showed that they had been injured by the borax. The corn on the control plots had the highest stand, but no injury was apparent to the corn on the borax or colemanite plots. The potatoes on the 40-ton borax-treated plot showed a slight yellowing of the leaves. The potatoes on the other plots were apparently normal.

On this date the beans on the 16-ton borax-treated plot had outgrown the initial injury, and the three other crops on this plot were normal. The colemanite-treated manure at the 16-ton rate caused no injury to any of the vegetables. On the 16-ton control plot all the plants were normal, but the beets were thinner than on the 16-ton colemanite-treated plot.

TABLE XI.—*Percentage of total boron as boric acid in potatoes, corn, beets, and string beans, dry basis, Bethesda, Md., 1915*

POTATOES

Boric acid added to upper 6 inches of soil.	Material.	Solids.	Total boron as boric acid found.
Per cent.		*Per cent.*	*Per cent.*
0.00176 as borax (16-ton plot)	Tops		Trace.
	Roots		0.000320
	Tubers	19.11	.000004
0.00264 as borax (24-ton plot)	Tops		.001000
	Roots		.000280
	Tubers	17.01	.000006
40-ton control plot	Tops		.000500
	Roots		.000400
	Tubers	15.51	.000004

CORN

0.00176 as borax (16-ton plot)	Stalk		0
	Ears [1]	85.5	.00004
	Roots		0
0.00264 as borax (24-ton plot)	Stalk		0
	Ears	66.74	.00007
	Roots		0
40-ton control plot	Stalk		0
	Ears	84.36	.00005
	Roots		0

BEETS

0.00176 as borax (16-ton plot)	Tops		0
	Roots	11.95	.000002
0.00264 as borax (24-ton plot)	Tops		0
	Roots	13.45	.000022
40-ton control plot	Tops		0
	Roots	10.36	.000012

STRING BEANS

0.00176 as borax (16-ton plot)	Beans and pods	11.39	0.00004
	Tops	18.77	.00040
	Roots	27.44	.00006
0.0044 as borax (40-ton plot)	Beans and pods	12.63	.00001
	Tops	21.06	.00003
	Roots	32.08	.00006
0.00232 as colemanite (16-ton plot)	Beans and pods	10.31	.00001
	Tops	17.78	.00012
	Roots	30.49	.00004
0.0058 as colemanite (40-ton plot)	Beans and pods	10.41	.00001
	Tops	19.04	.00001
	Roots	28.26	.00001
16-ton control plot	Beans and pods	9.04	.00002
	Tops	19.81	.00008

[1] Nitrogen results=1.39, 1.57, and 1.18 per cent, respectively.

The 24-ton borax treatment decidedly injured both beets and beans, but no injury to corn or potatoes was apparent. On the 24-ton colemanite-treated plot beans were injured considerably and beets slightly, while corn and potatoes were normal.

The 40-ton borax treatment injured all the plants; beans and beets severely and corn and potatoes slightly. The 40-ton colemanite treatment injured beans and beets only. The 40-ton control plot did not produce as good crops as the other control plots.

The corn on all control plots showed the highest stand, although the other plots showed no apparent injury. The potatoes showed no injury, except a slight yellowing of the leaves on the plants grown on the 40-ton borax-treated plot.

During October, 1915, the crops were harvested and samples from each plot were taken for analysis. Soil samples 6 inches deep were also taken from each plot at this time. The potatoes from the three borax-treated plots made 3¼ bushels, from the three colemanite-treated plots 2¼ bushels, and from the three controls 2⅛ bushels. Analyses of potatoes, corn, beets, and string beans from several of the plots are given in Table XI. It is evident from this table that the plants grown on the 24- and 40-ton borax-treated plots took up slightly more boron than those grown on the 16-ton borax-treated plot. The roots and tops of the potatoes contained more boron than the tubers in all the samples tested. The corn showed the presence of boron in the ears only. All of the beet samples analyzed showed the presence of minute amounts of boron in the roots, but none in the tops. The string beans and pods were analyzed together. Separate analysis of tops and roots were made. The tops contained more boron than the roots, and the beans and pods the least. The beans did not seem to take up the boron in proportion to the amounts added to the soil, as less boron was found in the plants grown on the 40-ton than in those on the 16-ton plots. The amounts found were small in all cases, owing to the fact that the samples were taken in October and the severely injured plants, which contained the comparatively large amounts of boron, had died earlier.

Peligot (*8*), in 1876, tested the influence of boron on beans. He used borax, boric acid, and potassium borate, 2 gm. per liter. The leaves turned yellow and all the plants were killed.

Haselhoff (*5*) grew beans in culture media containing borax and boric acid. A spotting of the leaves was observed, but this does not necessarily indicate an injury to plant growth. Boron was detected in the straw, but not in the beans.

The figures for solids in beans and pods showed higher results for the treated than for the control samples.

THIRD YEAR OF THE EXPERIMENTS, 1916

The beets, corn, beans, and potatoes were removed during October, 1915, and the ground was prepared for a third application of manure containing added borax and colemanite. The amount of manure and the treatments were identical with the two previous ones. After the manure had been applied to the plots, they were plowed and harrowed. On November 3 rye was planted on all the plots and the ground reharrowed.

On November 29 the rye had germinated and appeared 2 inches above the ground. The rye on the control plots was not affected by the heavy applications of manure, but on the colemanite-treated plot, 40-ton application, the rye showed a red tinge at the base of the leaf and stems. The tips of the leaves were green. The plants on the 24-ton colemanite-treated plot showed this reddish tinge to a slight degree, while the plants on the 16-ton plot were normal. On the borax-treated plot, 40-ton rate, a slight reddish coloration of the leaves was observed. This was not quite as noticeable as on the corresponding colemanite-treated plot. Plants on the 16- and 24-ton borax-treated plots were normal.

During the spring of 1916 the initial coloration of some of the plants on the heavily boron-manured sections disappeared, and throughout the growing period in the spring it was impossible to detect any difference in the rye on the various plots. It was found necessary on harvesting the rye on June 27 to cut it with a scythe, as the wind and rain had beaten down a great deal of it. The rye from each plot was stacked separately, and 100 heads were picked at randon from each of the nine plots. The total weights of the straw and grain from each plot were also taken. The weights are given in Table XII, together with analyses of the rye heads and rye straw from each plot for moisture, fat, nitrogen, and boric acid. It is evident from the weights of straw and grain that the best yields were obtained from the 16-ton plots, while the 40-ton plots gave the lowest yields. The total weight of the straw from the three plots receiving the same treatment showed but little difference—that is, from the borax-treated plots 820 pounds of straw and grain were obtained; from the colemanite plots 725 pounds (on two of the plots the straw was beaten down), and from the three control plots 800 pounds (the straw was beaten down on one of the three plots). The striking fact is that the yields from the three control plots showed the same tendency to decrease with an increased application of manure as from the boron-treated plots, which indicates that the increased amounts of manure rather than the boron were the determining factors. The weights of the 100 heads of rye given in Table XII are slightly larger for the control samples than for the heads grown on either the borax or the colemanite manured plots. The weight of 100 heads from the 40-ton borax-

treated plot was greater than from the 16- or 24-ton borax-manure plots, while in the colemanite and control plots the weights of 100 heads from the three plots of each series were very uniform. It is evident that the grain from the control plots was better filled out than from the other plots, and an examination of a large number of heads from all plots proved this to be so.

In brief, the fact that the heads of rye were not filled as well from the two series of boron-manured plots as from the controls and the slight red coloration of the plants during the first few weeks of growth are the only evidences obtained of any injurious action of boron. The total yields of straw and grain appeared to be influenced by the amounts of manure rather than by the boron added to the soil, the yields from the three plots heavily treated with manure being much lower than from the three plots receiving light applications of manure.[1]

TABLE XII.—*Analyses of rye, dry basis, Bethesda, Md., 1916*

HEADS

Boric acid added to upper 6 inches of soil.	Weight of 100 heads.	Moisture.	Fat.	Nitrogen.	Total boron as boric acid found.
Per cent.	*Gm.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.00176 as borax (16-ton plot)	128.4	9.27	1.34	2.05	0.0001
0.00264 as borax (24-ton plot)	141.1	9.30	1.38	2.24	.0002
0.0044 as borax (40-ton plot)	151.2	9.31	1.34	2.46	.0006
0.00232 as colemanite (16-ton plot)	141.0	9.31	1.37	2.18	.0004
0.00348 as colemanite (24-ton plot)	138.0	9.32	1.29	2.22	.0003
0.0058 as colemanite (40-ton plot)	141.0	9.30	1.41	2.22	.0004
16-ton control plot	157.5	9.28	1.24	1.95	.0001
24-ton control plot	152.3	9.31	1.34	2.04	.0001
40-ton control plot	158.6	9.34	1.26	2.27	.00015

STRAW

	Pounds.				
0.00176 as borax (16-ton plot)	315	9.41	1.05	0.93	0.00055
0.00264 as borax (24-ton plot)	265	9.45	.83	1.23	.00110
0.0044 as borax (40-ton plot)	240	9.41	1.04	1.39	.00196
0.00232 as colemanite (16-ton plot)	340	9.48	.97	.98	.00022
0.00348 as colemanite (24-ton plot)	[a]210	9.49	.99	1.10	.00035
0.0058 as colemanite (40-ton plot)	175	9.48	1.07	1.15	.00080
16-ton control plot	340	9.48	1.20	1.11	Trace.
24-ton control plot	300	9.53	1.22	1.08	.0001
40-ton control plot	[a]160	9.49	1.24	1.25	.0002

[a] Straw beaten down by wind and rain.

The moisture and fat results for the rye heads reported in Table XII are very uniform. The nitrogen results show a decided rise with the increased amounts of manure added to the borax-manure and control plots. More boric acid was found in the rye heads grown on the 40-ton

[1] The assistance of Mr. R. H. Hutchison, of the Bureau of Entomology, in supervising the planting and harvesting of the rye and in reporting the findings to the writer is gratefully acknowledged.

borax-treated plot than on the 16- or 24-ton plots. The amounts of boric acid found in the heads from the colemanite-manure plots were practically the same in the three cases. Small quantities of boric acid were found in the heads from all three of the control plots.

Similar determinations are given for the straw taken from all of the plots. The moisture results are very uniform for the nine samples, while the fat figures are a little higher for the three control samples than where boron was added to the soil. The nitrogen results show a marked increase, varying directly with the amounts of manure applied to the soil. The results for boric acid show that the rye took up the boron from the different plots in proportion to the quantities of boron added to the soil. On the other hand, the form in which the boron was added had a decided influence on the amounts absorbed by the plants, over twice as much boron of the readily soluble borax being absorbed by the plants as when the boron was added as the insoluble colemanite (calcium borate).

The control samples showed the presence of small amounts of boron.

ANALYSES OF SOIL, BETHESDA, MD., 1914–15

Samples of soil were taken 6 inches deep from the different treated and untreated plots. The samples were taken three times—that is, just prior to the second and third applications of manure and at the time of harvesting the third crop, eight months after the third application of the manure to all plots. The total nitrogen and the volatile nitrogen results obtained on distilling with magnesium oxid (see Table XIII) vary considerably for the different years, but the samples taken from all the plots on the same dates are rather uniform. The results for volatile nitrogen by the Folin aeration method are higher in the samples taken on June 1, 1915, after the first addition of manure to the soil, than in the samples taken on September 3, following the second addition, or in the samples taken on June 1, 1916, after the third manure treatment. The reduction in the control samples makes it evident that the boron was not the cause of the decrease. The nitrate results show the same tendency to decrease in each succeeding set of samples from June, 1915, to June, 1916, as was noted before for ammonia. There is no apparent reduction in either the ammonia or nitrates from the added boron.

No acid-soluble boric acid was found in any sample. The largest amounts of total boric acid were found in the samples taken on September 3, 1915, only two months after the second application of the manure, while with the samples taken on June 1, 1915, and June 1, 1916, seven months had elapsed since the addition of the boron-manure to the soil. No more total boric acid was found in the soil samples taken in June, 1916, after the third application of boron-manure than in the samples taken in June, 1915, following the first application of boron-manure to the plots. In view of this, and also as the most boron was found in the

samples taken on September 3, 1915, two months after the second addition of boron-manure to the soil, it is evident that the boron gradually disappeared from the upper 6 inches of soil, and no cumulative action of boron resulted from the three successive additions of boron-treated manure to the same soil when 0.08 pound of borax or 0.095 pound of colemanite was added to the bushel and the manure applied to the soil at a rate of 40 tons per acre.

TABLE XIII.—*Nitrogen distribution and boron as boric acid in the soil, Bethesda, Md.*

[Samples of soil were taken from same plots following each of the three additions of manure and boron]

Treatment of soil.	Boric acid added to upper 6 inches of soil.	Nitrogen determined as—				Boron as boric acid found.	
		Total.	Ammonia (MgO method).	Ammonia (Folin method).	Nitrates.	Soluble.	Total.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
40-ton borax-treated plot [1]	0.0044	0.161	0.014	0.00070	0.00324	0	0.000112
40-ton colemanite-treated plot [1]	.0058	.161	.014	.00050	.00135	0	.00008
40-ton control-treated plot [1]	0	.154	.014	.00100	.00232	0	.000024
16-ton borax-treated plot [2]	.00176	.119	.042	.00033	.00282	0	.00048
40-ton borax-treated plot [2]	.0044	.168	.042	.00050	.00286	0	.00048
16-ton colemanite-treated plot [2]	.00232	.119	.042	.00063	.00116	0	.00040
40-ton colemanite-treated plot [2]	.0058	.168	.028	.00066	.00208	0	.000024
16-ton control-treated plot [2]	0	.119	.042	.00066	.00156	0	.00012
16-ton borax-treated plot [3]	.00176	.140	.014	.00060	.00091	0	.00008
24-ton borax-treated plot [3]	.00264	.204	.014	.00060	.00144	0	.00012
16-ton colemanite-treated plot [3]	.00232	.158	.014	.00050	.00100	0	.00004
40-ton colemanite-treated plot [3]	.0058	.196	.010	.00060	.00030	0	.00012
24-ton control-treated plot [3]	0	.189	.014	.00030	.00130	0	.00004

[1] Samples taken on June 1, 1915. Manure applied in October, 1914.
[2] Samples taken on September 3, 1915. Manure last applied in June, 1915.
[3] Samples taken on June 1, 1916. Manure last applied on November 1, 1915.

SECOND ANALYSES OF BORON-TREATED SOILS FROM THE SOUTH

In order to obtain information as to the length of time that boron remained in the soil, a second series of samples of soil from Orlando, Fla.; Dallas, Tex.; and New Orleans, La., were analyzed in June, 1916. These soils had received applications of manure plus borax and plus colemanite the year previous, and analyses of the soils for soluble boron have been reported (*2*). The results of the analyses are given in Table XIV.

In 1915 soluble boron was found in all of the Orlando and New Orleans samples and in two of the Dallas soil samples. In 1916 no soluble boron was found in the samples from any of the boron-manure or control plots. Only relatively small amounts of total boron were found in these soils in 1916. The samples from the boron-treated plots showed the presence of only a little more boron than the controls. The disappearance of the boron and the holding of the small amount present in an insoluble form is a remarkable demonstration of the power of the soil to absorb toxic substances and to hold them in an inactive form.

TABLE XIV.—*Percentage of total and soluble boron, nitrogen, and nitrates found in samples of soil from Orlando, Fla.; Dallas, Tex.; and New Orleans, La.*

Soils analyzed.	Soluble boron as boric acid.	Total boron as boric acid.	Total nitrogen.	Nitrogen as nitrates.
Orlando, Fla.:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Borax plot [1]	0	0. 00003	0. 056	0. 00572
Control plot	0	. 00002	. 056	. 00777
Dallas, Tex.:				
Borax plot (light)[2]	0	. 00001	. 208	. 00667
Borax plot (heavy)[2]	0	. 00001	. 295	. 00805
Control plot	0	0	. 253	. 00800
New Orleans, La.:				
Borax plot [2]	0	. 000040	. 084	. 00084
Control plot	0	. 00002 4	. 070	. 00090

[1] 0.75 pound of borax added per 8 bushels of manure; manure applied at 16-ton rate.
[2] 1.25 pounds of borax added per 8 bushels of manure; manure applied at 16-ton rate.

SUMMARY

The influence of single applications of horse manure containing borax or colemanite added at the respective rates of 0.08 and 0.095 pound to the bushel and applied to the soil at the rate of 16 tons per acre was tested on peach trees at Acampo, Cal., on barley at Walnut Creek, Cal., and on wheat at Benton Harbor, Mich. The upper 6 inches of soil on the borax-treated plots were calculated to have contained 0.00176 per cent of boric acid and that on the colemanite plots 0.00232 per cent.

No influence on the growth or yield of wheat or barley was observed, yet the boron seemed to have a beneficial effect on peach trees. There was no soluble boron and but little total boron in any of the soil samples from the three different localities.

Experiments were conducted at Arlington, Va., and Bethesda, Md., in which the horse manure treated with borax and colemanite was applied as noted above, but at three different rates per acre—that is, 16, 24, and 40 tons. The tests at the Arlington Experimental Farm extended over two seasons and at Bethesda over three seasons. The soil was calculated to have contained in the upper 6 inches when borax-manure was applied at the 16, 24, and 40 ton rates, 0.00176, 0.00264, and 0.0044 per cent of boric acid, respectively, and 0.00232, 0.00348, and 0.0058 per cent respectively, when colemanite was applied.

The first season at Bethesda 0.0044 per cent of boric acid as borax and 0.0058 per cent as colemanite caused no injury to lettuce, spinach, kale, or onions. These percentages of boric acid the first season at the Arlington farm caused a reduction in crop with lettuce, spinach, kale, and cabbage.

At Arlington 0.00264 per cent of boric acid as borax and 0.00348 per cent as colemanite reduced the yield of spinach and kale by preventing germination. The difference in the action of the same percentages of

borax and colemanite on the same crops at Arlington and Bethesda is rather striking. The colemanite and borax showed no difference in action on plants grown in the same soil the first season. More boron was found in the lettuce, cabbage, spinach, and kale plants grown on the 40-ton colemanite-treated plots than in the plants from the 40-ton borax-manure plots at Arlington. Onions grown at Bethesda showed the presence of boron only in the flowering tops of the plants grown on the 40-ton borax-treated plot.

The second season 0.00176 per cent of boric acid as borax injured string beans at both Arlington and Bethesda; 0.00232 per cent as colemanite at Arlington injured string beans, while at Bethesda this percentage of colemanite caused no injury; but 0.00348 per cent of boric acid as colemanite injured string beans at Bethesda. At Arlington 0.00264 per cent of boric acid as borax and 0.00348 per cent as colemanite reduced the yield of corn and turnips, but at Bethesda were apparently without effect on the yield of corn. At Bethesda 0.0044 per cent of boric acid as borax and 0.0058 per cent as colemanite reduced the yield of potatoes and corn.

The potatoes, corn, beets, and string beans grown at Bethesda contained but small amounts of boron. The turnips at Arlington contained more boron than the plants at Bethesda. It is evident that the vegetables took up more boron from the soil at Arlington than at Bethesda.

Rye was grown the third season at Bethesda following the third application of boron manure. A reddish tinge was observed in the young plants on the 40-ton boron-treated plots. This disappeared gradually, and in the spring the rye looked normal The rye heads grown on the boron plots were not as well filled out as the heads of the plants on the control plots. The crops on the 24- and 40-ton control plots were materially reduced by the large amounts of manure applied. The quantity of manure added was of more importance in reducing the yield than the added boron.

There is a decided difference in soils in rendering the added boron nontoxic to plants. This is seen in the divergent results as to plant injury, etc., obtained on adding equal amounts of borax or colemanite to different soils. In some cases boron is taken up by plants from soil when no detectable quantities of boron are present in the soil samples.

There is a complete disappearance of detectable amounts of soluble boron from soils after the addition of borax and colemanite, although small amounts of total boron are present. It is therefore evident that insoluble boron compounds are formed. In many soils there is a tendency for plants to absorb boron in proportion to the quantities added. In some soils the same amounts of boron were absorbed irrespective of the quantities added. The calcium of the colemanite did not prevent the

absorption of boron, although usually more boron was absorbed by the plants when the boron was added as borax than as colemanite. The amount of boron absorbed by plants depends on the character of the soil more than on the form in which the boron was added.

The absorption of boron by plants varies with the variety of plant, the solubility of the boron compound, the quantity of the boron compound added to the soil, the time elapsing after the compound is mixed with the soil before planting, the amount of rainfall, etc., and finally with the character of the soil to which the boron compound is added.

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VIVIAN MAIER

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